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Space Station Communications

Marjory J. Johnson

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The Space Station will be a permanently manned facility in space. It will be placed in orbit in the early 1990s. The philosophy which provides the foundation for the development and design of the Space Station also imposes unique requirements on the Space Station communications system. The purpose of this paper is to describe the Space Station environment, emphasizing the role of communications, and to discuss the requirements which must be satisfied by the Space Station communications system.

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Space Station Communications

Marjory J. Johnson
Research Institute for Advanced Computer Science
NASA Ames Research Center
Moffett Field, California 94035

1. Introduction

In his 1984 State-of-the-Union Address President Reagan called for the development of a permanently manned facility in space, a Space Station, to be established within a decade. This Space Station will be a cooperative venture among free-world nations to utilize the space environment for the advancement of science. Activities which will be conducted from various components of the Space Station System include scientific experiments, observations of the earth and its atmosphere, and processing of materials for which the manufacturing procedure either requires or is facilitated by the unique environment of space.

Communications is a vital part of the Space Station System. First, communications is necessary for operational control of the Space Station, i.e., for navigation, environmental control, and life-support functions. Second, it must support customer payload operations. That is, data generated from scientific experiments and processing activities must be collected, processed, and stored on the Space Station and/or delivered to a customer located at a ground facility. Vice versa, control commands from the customer must be transmitted to his payload. The combination of all end-to-end data management services for Space Station customers, from the payload site to the customer located at his own facility on earth, is called the Space Station Information System (SSIS). The subset of SSIS which consists of standard services that are offered to all users and "core" services that are necessary for proper functioning of the Space Station is called the Space Station Data System (SSDS).

This paper describes the Space Station environment and the unique requirements this environment imposes on the Space Station communications system. The information contained herein was compiled from NASA-sponsored contractor studies to define requirements of the SSIS and the SSDS, conducted by TRW [6], McDonnell Douglas Astronautics Company [2], and the Jet Propulsion Laboratory [1].

2. Physical Architecture of the Space Station

The expected lifetime of the Space Station System is twenty years. In this section we describe the Space Station System components which have been identified for its initial configuration.

The Space Station will be a permanently manned vehicle in low earth orbit. It will be a modular structure consisting initially of five modules, including two habitation modules, two laboratory modules, and a logistics module. The Space Station forms the hub of the Space Station System. Other elements of the system will include orbiting space platforms and satellites which will be used as a base for customer payloads, vehicles used to launch customer payloads from the

Space Station, a shuttle for transportation between the Space Station and ground, satellites for navigation and for communication to earth, and ground facilities for control of the Space Station System and for data handling. A brief description of each of these elements is given below.

There will be two types of orbiting space platforms, Co-orbiting Space Platforms (COPs) and Polar Orbiting Space Platforms (POPs). The Space Station System may include one or more platforms of each type, and each platform will support multiple payloads. Co-orbiting Space Platforms will be in low inclination, low earth orbit, constantly within line-of-sight of the Space Station; initial payloads will be primarily astronomical and solar observations. Polar Orbiting Space Platforms will be in sun-synchronous orbit; they will be used primarily for earth and atmospheric observation. Some customers may require that their payloads be physically isolated, rather than sharing the facilities of a COP or POP. Such payloads will be launched into orbit as separate satellites, called Free Flyers (FFs).

Orbital Maneuvering Vehicles (OMVs) and Orbital Transfer Vehicles (OTVs) will launch payloads into orbit from the Space Station and will return them to the Space Station for repair and servicing. Both types of vehicles will be equipped with manipulators and grapplers for handling of the payloads in space. The two facilities will differ primarily in their propulsion capabilities. OMVs will be used to transport and service payloads which are mounted on a COP or to launch and retrieve other payloads located in low inclination, low earth orbit, whereas OTVs will be used to launch payloads to high energy orbits (e.g., geostationary orbits), to launch interplanetary missions, to service the POPs from the Space Station, and to place or service payloads in intermediate inclination orbits.

The Shuttle Transportation System (STS), or the Shuttle Orbiter, will handle all ground-to-orbit (i.e., low earth orbit) transportation. The shuttle will be the primary means for launch, access and resupply for the Space Station System. Payloads may be launched into orbit in two different ways. They may be transported to the Space Station by the STS and then launched into other orbits from there by either an OMV or an OTV (as described above); or they may be launched into low-altitude orbit directly by the STS. The Free Flyers may or may not be launched into orbits accessible from the Space Station via the OMV and OTV, and hence may or may not be considered part of the Space Station System. For security purposes many Department of Defense satellites, foreign satellites, and even commercial satellites may not wish to be operated as elements of the Space Station System. They may operate completely independently of the Space Station System, or they may enter the SS System only for servicing.

An Extravehicular Maneuvering Unit (EMU) is another term for an astronaut in a space suit performing an extravehicular activity. The astronaut will require both voice and video communication with the Space Station.

When the Space Station is first placed into orbit, the primary means of communication between all the space elements of the system and the ground will be a system of communications satellites, called the Tracking and Data Relay Satellite System (TDRSS) [5]. The TDRSS link will permit almost continuous communication, with the exception of a small zone of exclusion over the Indian

Ocean. The TDRSS ground relay station is the White Sands Ground Terminal (WSGT), located at White Sands, New Mexico. NASCOM (the NASA communications network) provides the principal link to other ground stations and customer facilities.

Limited backup for TDRSS will be provided by both the Deep Space Network (DSN), which will also provide a communication link to the OTV when it is out of range of the Space Station, and the remaining facilities of the Ground Spaceflight Tracking and Data Network (GSTDN), a ground-based network of tracking stations which provided the sole means of communicating with and tracking spacecraft before the existence of TDRSS [5].

The Global Positioning System (GPS) is a system of satellites emitting signals, which allow accurate determination of position and velocity. The Space Station, the platforms, the OTV, the OMV and the Free Flyers will all navigate using the GPS.

Control centers for the various Space Station space elements are located on the ground. These include the Space Station Operations Control Center (SOCC) and one or more Payload Operations Control Centers (POCC). These control centers will provide ground support for the Space Station System.

Glossary of Terms

COP	Co-orbiting Platform
DSN	Deep Space Network
EMU	Extravehicular Maneuvering Unit
FF	Free Flyer
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
GSTDN	Ground Spaceflight Tracking and Data Network
OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
POP	Polar Orbiting Platform
POCC	Payload Operations Control Center
SOCC	Space Station Operations Control Center
SS	Space Station
SSDS	Space Station Data System
SSIS	Space Station Information System
STS	Shuttle Transportation System
TDRSS	Tracking and Data Relay Satellite System
WSGT	White Sands Ground Terminal

3. Space Station Users

The Space Station will be oriented toward providing services for its customers, those who are conducting experiments or materials processing using Space Station System facilities. A second group of Space Station System users, called core users, will maintain the facilities. Each category of users requires communications services from the Space Station System, including transmission of data and commands, data storage and data management, monitor and control functions, data processing, guidance and navigation, and scheduling.

Examples of anticipated customer payloads are scientific experiments, observations of the earth and its atmosphere, and development of industrial processes in space. There will be three classes of customers: commercial customers (i.e., private industry), military users, and non-profit users who are interested in the advancement of science (e.g., academicians and non-military government users). Specific payloads for commercial endeavors might include weather observations, agricultural crop observations, soil moisture observations, repair and service of communications satellites, and development of industrial processes in space. Non-profit customers might conduct earth observations, science experiments, solar energy research or solar physics research. Military payloads will probably require special security measures, possibly requiring the military to provide both their own free-flying satellites on which to base their payloads and their own communication links to ground.

Payloads may be based in several different locations, depending on the particular payload requirements. Some payloads may be located on the Space Station itself. Payloads requiring isolation from the Space Station will be located on one of the orbiting space platforms or on a free-flying satellite. Each space platform will serve as a base for multiple payloads. Payloads located on a COP will be easier to launch and service, because of their proximity to the Space Station. However, some payloads, e.g., earth-sensing payloads, require a polar orbit. These payloads will be located on a POP. If total isolation is required to prevent contamination or to enhance security, then the payload may be placed by itself on a free-flying satellite. This may be possible only if the customer is willing to assume financial responsibility for developing the satellite and placing it into orbit.

Customers of all types will require similar services from the Space Station Data System. Data will be collected and processed at the payload site, and then transmitted to the customer's home site, where it will undergo final analysis. Wherever the customer is located, whether on the Space Station, at a POCC, or at his home site, he will be able to control his payload interactively, subject to constraints of availability of bandwidth.

The function of core users will be to provide and maintain suitable facilities for use of the customers. Core support will be needed for navigation and attitude control, to plan the Space Station program, to monitor and control all the Space Station elements, to maintain the proper environment for the payloads, to regulate all life support facilities (such as water, food, health, recreation), and to provide other facility support functions such as electrical power and cooling.

Core users will require less communications capacity than the customers, since the amount of data generated by customer payloads is expected to be massive. However, core users will require greater reliability than the customers, since core users will be performing life-critical functions.

4. Major Communications Pathways

For its initial configuration (i.e., 1992 time-frame), the primary communication link between the space elements and ground elements of the Space Station System will be the Tracking and Data Relay Satellite System (TDRSS) [5]. TDRSS is a system of two geostationary relay satellites. A third satellite will function as a backup in case of failure. One or more channels on the TDRSS satellites will be dedicated to Space Station System use. They will provide almost continuous communication between space and ground elements of the Space Station System, with about a ten-minute gap in coverage over the Indian Ocean during each ninety-minute orbit.

There will be direct communications links between the Space Station and TDRSS and between the orbiting platforms and TDRSS. Thus, it will be possible to transmit experimental data from the platforms directly to ground via TDRSS. All constellation space elements (i.e., those elements which are co-orbiting with the Space Station) will have direct communication links with the Space Station. These links will be used for control of the constellation elements by the Space Station. Also, all end-to-end communication between the constellation elements, other than the COPs, and ground will be funneled through the Space Station. The links between the platforms and TDRSS will be necessary because of the massive amount of data that is expected to be generated by experiments based on the platforms. As an alternative, data from a COP could be transmitted to the Space Station before being sent to ground via TDRSS. This might be done, for example, if temporary storage were needed because of problems with TDRSS. This will not be possible with the POPs, because they will seldom be in line-of-sight with the Space Station.

The White Sands Ground Terminal (WSGT) will be the center of ground communications. All data from space to ground will be routed via the WSGT. Communication among ground-based elements of the Space Station System will be handled primarily via NASCOM (NASA Communications System).

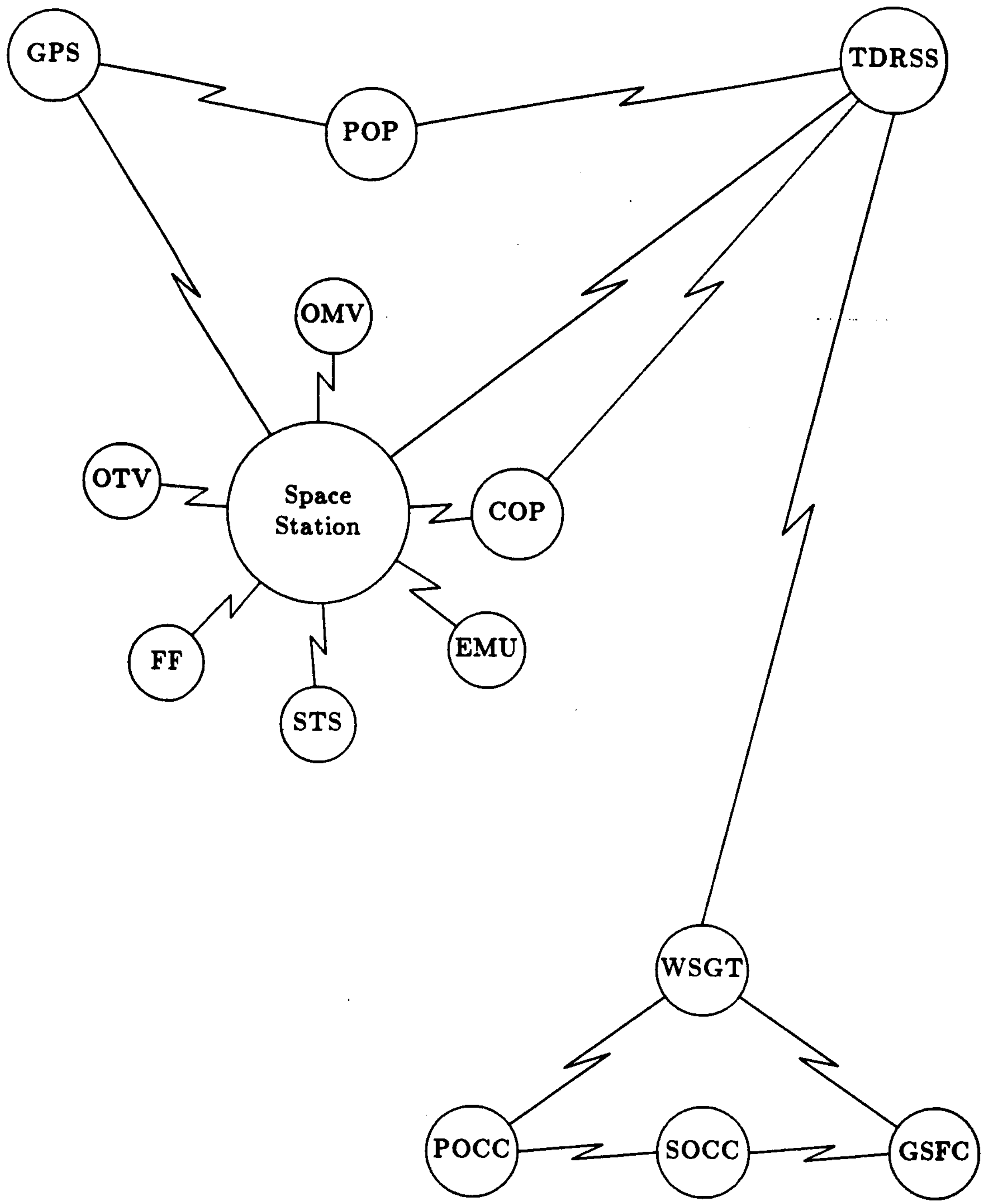
From the customer's perspective, the important communications link will be between his payload located in space and his location on the ground. Data will be collected at the payload site and then transmitted to WSGT via TDRSS. From White Sands, the data will be transmitted via NASCOM to a POCC. Connection to customer facilities will then be completed via other ground-based networks. Data analysis and data reduction may occur at the payload site and data may have to be stored temporarily, depending on the availability of bandwidth on TDRSS.

If the payload is located on a Free Flyer, the customer may communicate with it via the Space Station (if the Free Flyer is in direct line of sight with the Space Station), or he may wish to provide his own communication pathways independent of the Space Station System.

Ways in which the capabilities of the TDRSS system may be extended in the growth phase of the Space Station System include providing greater bandwidth, eliminating the zone of exclusion over the Indian Ocean, and providing multiple downlinks so as to enable direct communication with major ground facilities in the United States and possibly in Europe and Japan.

Both control data and payload data will share the TDRSS channels between space and ground. Control information must be received in a timely fashion. In addition, although some payload data may be stored for later transmission whenever there is a TDRSS channel available, a requirement for real-time interactive control of payloads from the customer's remote location has also been specified, including the real-time transmission of audio and video signals. This will require careful scheduling of the TDRSS channel usage. An identified goal for the Space Station is to make the space elements of the system autonomous and thus to minimize space to ground communications. As the Space Station evolves, control functions will migrate from ground to space, so that downlink transmission at that time may be primarily payload data for customers.

The figure below depicts the initial configuration of the Space Station System. Only the major communications pathways have been included. Each single constellation element that is pictured is intended to represent the existence of one or more elements of that type within the Space Station System. Some of these constellation elements, such as the Free Flyer and the Orbital Transfer Vehicle, may be growth elements, instead of being part of the initial Space Station configuration. The primary architectural difference between the Space Station System as pictured in this figure and as envisioned in the 2010 time-frame is the inclusion of more copies of the same elements and the inclusion of more communication links between the expanded TDRSS and ground stations.



Space Station System Communication Links

5. Space Station Communication Requirements

General Space Station requirements have a direct impact on Space Station communications. Requirements that have been identified by the TRW and McDonnell Douglas contract teams* include modularity, expandability, flexibility, automation, autonomy, reliability, and adherence to standards. Cost-effectiveness is, of course, an underlying requirement in all aspects of Space Station activity.

5.1. Modularity and Expandability

The Space Station will evolve gradually over its twenty-year lifetime. To support the expected growth, the Space Station will have a modular structure. Types of modules will include habitation modules, laboratory modules, control modules, energy modules, and logistics modules. In its initial configuration the Space Station will consist of five modules; it is expected eventually to grow to approximately twenty-four modules. As the Space Station grows, some of the additional modules will be replicas of existing modules, while others may be new types of modules that have not yet been envisioned. Modularity of the SSDS is necessary to support the modular structure of the Space Station and to facilitate the accompanying expansion of communication services. For convenience and ease of construction, physical boundaries of SSDS modules probably will

*TRW and McDonnell Douglas Astronautics are the primary contractors for the first phase of Space Station activities. This phase, soon to be completed, is a feasibility study. Additional phases include the preliminary design phase, now in progress, and the construction phase.

correspond with physical boundaries of Space Station modules.

To support both the modular growth of the Space System and the continual changing of customers and their payloads, payloads and/or Space Station modules will be transported via the Shuttle to the Space Station, where final assembly, testing, and integration will occur. This is called "on-orbit" integration. Some payloads and space facilities may actually be constructed on the Space Station. On-orbit integration will be necessary for communication facilities also.

Another type of modularity under consideration is the physical separation of core functions from customer functions through the use of separate data busses and separate computational facilities. Separation of core and customer functions would enhance reliability, since it would prevent customer functions from interfering with critical life support functions and other critical core functions. Such a separation would also increase the flexibility of the SSDS so that it could easily adapt to the constant changing of payloads.

5.2. Flexibility

Flexibility is required to support the evolution of the Space Station Data System. In addition to physical growth of the Space Station System as the number of modules increases, other types of change must be accommodated. Space Station customers will be continually changing; as a result the nature of customer payloads may change dramatically over the lifetime of the Space Station. The Space Station System must be able to adapt to and to satisfy the customers' needs, whatever they may be. Equally important, the Space Station Data System is to use state-of-the-art technology and must be designed so that new technological advances can be easily incorporated as they become cost-effective to use. Growth and change in the Space Station Data System also includes automation of functions, relocation of functions, migration of support and control of functions from ground to space, and expansion of services.

5.3. Automation and Autonomy

The Space Station is to be permanently manned, although there may be short periods of unmanned activity, especially in the early phases. Both because of and in spite of the presence of human beings, automation is one of the primary design requirements for the Space Station Data System. This means that selected systems or processes will be mechanized to function without human intervention. Automation is required because of the presence of human beings, since automation of critical life support functions is deemed necessary for reliability. Automation is required in spite of the presence of human beings, since the crew has been identified as one of the scarcest resources on the Space Station. Crew size is anticipated to be small. The initial crew will consist of perhaps two station specialists and four mission specialists. Crew size will increase to about sixteen or more as the Space Station evolves. Automation will allow crew members to spend their time doing challenging work rather than handling routine maintenance chores.

Autonomy of the Space Station is a requirement that is closely related to automation. A system is autonomous if it can function without outside control.

The degree of Space Station autonomy from ground control is to be maximized, but ground control must always retain full back-up capability. Autonomy will enhance reliability of critical functions, such as life support functions, and it will reduce communication between space and ground, but it will increase the demand for on-board memory. Although the above definition of an autonomous function does not explicitly exclude human participation in the function, that is the general interpretation. Hence, automation is a key ingredient for establishing autonomy.

The levels of automation and autonomy of the SSDS will increase as the Space Station evolves. Functions which will be made autonomous and automated are those which are performed routinely, are vital for life support, and are time-consuming for the crew to perform. Specific potential areas for automation include monitoring and control of the Environmental Control and Life Support System on the Space Station; navigational functions such as guidance and attitude control; and monitoring, fault diagnosis, and reconfiguration of SSDS elements. The ultimate goal is to apply artificial intelligence and expert system technology to automate the Space Station Data System as much as possible, with provisions for manual backup of all automated functions from the ground. Benefits of automation include enhanced reliability and reduction of crew time spent on routine tasks; some disadvantages are increased traffic for the SSDS and increased complexity of the system.

5.4. Reliability

Permanent support of human life on the Space Station means that the life support system and other critical Space Station Data System functions must be reliable. This implies the need for a high level of redundancy and also for automatic reconfiguration of the Space Station Data System to bypass faults. The primary means of repair of equipment on the Space Station has been identified as replacement. This includes the presence of hot backups, cold backups, or simply spare parts for replacement. The level of backup would depend on the criticality of the function being supported. Faulty parts or units will be transported back to earth for repair. Because of the critical nature of the life support system, monitoring and control of the system has been identified as one of the key areas for automation.

Fault tolerance of the Space Station Data System is an important aspect of the reliability requirement. The SSDS must be able to detect faults, isolate faults, and either correct the problem or reconfigure the system to bypass the problem. The reliability of TDRSS is a critical issue. To guard against loss of data if TDRSS is not continuously operational, on-board data storage capabilities must be great enough to accommodate data generated during an entire ninety-minute orbit.

5.5. Standards

Use of standard interfaces, elements, and procedures is another requirement for the SSDS. In general, adherence to standards reduces cost and ensures long-term support and availability of products. An issue currently being studied is the proper level of adherence of the Space Station communications network to the International Standards Organization (ISO) Open Systems Interconnection (OSI) network model.

5.6. Control Requirements

Each space-borne component of the Space Station System requires control. Hence, platform control, OMV control, and OTV control have all been identified as Space Station Program Elements. Part of each control function will be located on the Space Station and part will be located on the ground, at the SOCC and the POCCs. Complete backup control capability must be located on the ground.

When the Space Station is first placed into orbit, control and monitoring of Space Station components will probably be ground-based. As the Space Station evolves, more and more of these functions will be migrated to the Space Station, with the ultimate goal of complete autonomy of the Space Station. However, to ensure crew safety, backup control capability must always be present on the ground.

The tool for monitoring and control of all Space Station Information System functions has been identified as a multipurpose applications console (MPAC). An MPAC will be a sophisticated workstation, with all-encompassing capabilities. It will support both graphics and text output, and it will support voice interactions during docking operations and for management of some payloads. There will be local computational capability, local storage, local database management, and provision for hardcopy output. The SSDS will support a large number of MPACs, at least some of which will be portable so that they can be shifted from location to location as needed. Because of the importance of the MPACs, backup will be provided.

MPACs will be present both on board the Space Station and on the ground. Operators on the Space Station and at Mission Control on the ground will control Space Station activities via the MPACs. Functionally, the MPAC must support the following tasks: hardware maintenance, software development and maintenance, control of all Space Station System components, docking operations, extra-vehicular activity monitoring, avionics management, logistics, unmanned operations, emergency handling, facilities management, crew training, planning and scheduling of Space Station activities, and coordination of customer activities.

5.7. Networking Requirements

The Space Station communications network presents many challenges. Many design constraints are necessitated by the requirements listed earlier in this section. In addition, a diverse workload must be supported. This workload consists of two parts, customer traffic and core traffic, each having different characteristics. Customers themselves will have diverse communications requirements, because of the diversity of their payloads. Customer payloads will generate massive amounts of data, necessitating requirements for high bandwidth communication and for high storage capacity. New developments in mass storage technology may be needed to satisfy these requirements. In contrast, core functions will have low-traffic needs, but will require deterministic and bounded delay for life-support functions.

The Space Station Data System will be oriented towards the customer. For the first time, customers will be able to communicate interactively with their payloads in space. A workstation is being designed to provide a user-friendly human interface, to accommodate the customer's needs and also the needs of crew members who will not be computer experts.

The architecture of the Space Station communications network has not been determined. Fiber optics has been proposed as the transmission medium because of its light weight, its high bandwidth, and its resistance to electro-magnetic interference. Two fiber optic network implementations that are currently being studied are a star network with a passive center and a token ring. The star network, called Fiber Optic Demonstration System (FODS) [7], was developed by Sperry Corporation, under contract to Goddard Space Flight Center. The Fiber Distributed Data Interface draft proposed ANSI standard for a token ring [3] is being implemented by Honeywell, under contract to Johnson Space Center. An alternate type of network implementation suggested by TRW is to use point-to-point fiber-optic links where high bandwidth channels are required and to use a broadband bus with frequency division multiplexing for all other on-board networking needs. All of these network implementations would provide the desired deterministic and bounded delay.

The need for management and control of local area networks is now widely recognized; it is of utmost importance in the space environment. Relevant functions include fault detection and isolation, monitoring of general network performance (both to determine how efficiently the system is operating and to plan for future growth), and configuration [4]. Since the Space Station network must be virtually self-governing, these network control functions must be automated.

6. Space Station Communications Scenario

The Space Station System will provide a futuristic working environment. A snapshot glimpse of activity on the Space Station System when it is fully operational might look like this:

The Space Station is buzzing with activity. A dozen crew members are living and working there. The Shuttle has just arrived from earth and is performing docking maneuvers. A crew member inside the Space Station is sitting at a workstation to supervise the operation. He watches the docking maneuvers on his screen and sends navigation commands to the Shuttle. During the entire procedure he maintains constant voice communication with the Shuttle crew members. This was a routine trip for the Shuttle, to deliver new crew members to begin their ninety day tour of duty and to replenish supplies of food and medicine on the Space Station. The Shuttle is also delivering an interplanetary probe, which will be assembled and tested on the Space Station, and then launched to outer space by the Orbital Transfer Vehicle. When the Shuttle departs, it will carry some crew members who have completed their tour of duty back to earth.

At a berthing location at another part of the Space Station System, an Orbital Maneuvering Vehicle is preparing to depart from the Space Station to retrieve a customer payload from a Co-orbiting Platform. The experiment has been completed and the equipment will be returned to the customer on earth.

In still another part of the Space Station System an astronaut is performing an extravehicular maneuver to repair a robot arm. He is transmitting video pictures and verbally explaining details of his repair work to a crew member, who is sitting at a workstation inside the Space Station.

Another workstation is automatically monitoring activity on the Space Station communications network. A problem with one of the on-board processors is detected. The system reconfigures itself automatically, substituting a backup processor for the one that has failed. Information relating to the problem is stored in a data base for future study by crew members. The failed processor will be shipped back to earth for repair or replacement when the Shuttle returns to earth.

Meanwhile, back on earth, a scientist at his home facility sits at a workstation similar to the ones located on board the Space Station. He is observing sun-spot activity by examining data as it is collected by instruments located on a Co-orbiting Platform. Noticing increased sun-spot activity and desiring to examine the phenomenon more closely, he enters a command which interactively doubles the data collection rate of the instrument.

At Mission Control only a few people are on duty, in contrast to the army of people who supervised space missions in the past. These people are monitoring Space Station System activity, and they have the capability to override automatic control of the Space Station System. However, they provide only backup control, since the Space Station System functions autonomously.

7. Conclusion

The Space Station communications environment is unique. It provides many fertile areas for research to meet the challenges it presents. Among these challenges are integration of voice and video in the same network, effective and efficient use of high bandwidth networking, transmission and storage of massive amounts of data, design of reliable systems, unprecedented level of automation and autonomy, incorporation of expert systems, provision of interactive remote control of activities located in space, design of sophisticated workstations and of a user interface for these workstations, and design of a flexible system that can support evolution of the Space Station. The Space Station will be placed into orbit long before all these challenges are met. However, the capabilities of the Space Station will be constantly enhanced as it evolves.

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**This reference is intended to include all associated technical reports by various members of the contract team.